# RENEWAL OF A CHLORIDE-DAMEGED RC HOLLOW SLAB BRIDEGE

## －MATSUSHIMA VIADUCT ON HANWA EXPRESSWAY－


**Shozo NISHIYAMA*[1]**
**Tetsuo MATSUDA*[2]**
**Shin MIYAZATO****

*West Nippon EXpressway Company limited**
*1-13 Iwakuracho, Ibaraki, Osaka, Japan 567-0871*
*Kanazawa Institute of Technology***
*7-1 Ougigaoka, Nonoichicho, Ishikawagun, Ishikawa, Japan 921-8501*
*s.nishiyama.aa@w-nexco.co.jp*[1]*
*t.matsuda.aa@w-nexco.co.jp*[2]*
*miyazato@neptune.kanazawa-it.ac.jp***



**ABSTRACT**

Matsushima viaduct on Hanwa expressway has been experiencing severe deterioration on its structural health through over thirty years service. The superstructure is four-span RC continuous hollow slab and was overlaid with steel-fiber reinforced concrete in 1990 to meet the growing heavy traffic. Even after the reinforcement, the functionality of the bridge was lost rapidly by suffering from heavy traffic and chloride content that was contained initially and being supplied by wind from sea. Finally it was found that a drastic treatment must be executed on the bridge to reinforce the superstructure.

The preliminary in-depth survey with nondestructive evaluation including loading test gave the following conclusions, (1) the chloride content significantly exceeded the standard and corrosions on reinforcing steel bars were developing, (2) the static elasticity coefficient of concrete was significantly declined as well as the rigidity of all girders, and (3) delamination between the base concrete and overlay concrete was found and that was across a wide area of the upper side of slab. A wide range of possible countermeasures, including replacing the entire bridge were considered, and it was decided to remove the upper part of slab by water-jet and replace it. This newly developed partial repairing method enabled it to extend the lifetime of the bridge as well as to recover and improve the bridge's functionality with minimum traffic control. The countermeasure for macro-cell corrosion caused by high chloride content and the difference

of electric potential between initial concrete and secondary concrete newly placed was also introduced and it is on the process to acquire a potent for the method. The methods applied in this project are considered to be highly applicable to other bridges which are in similar condition as this bridge.

## 1. Introduction

Matsushima Viaduct was constructed in Wakayama-shi in 1973 as a part of Hanwa expressway and has been playing important role by connecting Osaka and Wakayama. In 70s economic activity of Japan was growing rapidly and lack of aggregates was one of serious problems which many construction projects were facing in those days. To catch up with the demands for highways, sand aggregates were taken from beach or bottom of sea, which should have caused corrosion on reinforcing steel bars, and Matsushima Viaduct was one of the structures constructed with sea sand.

The bridge is now carrying 17,000 vehicles per day (including 2,800 large-sized vehicles) and sodium chloride is used as de-icing agents with 0.43kg/$m^2$ per year. Similarly as other bridges in Japan, potholes in pavement, corrosion of steel bars and cracks at lower side of slab were observed around 1988, which may have been caused by growing weight of traffic and aging of members. As the countermeasure, steel fiber reinforced concrete was overlaid on the slab with thickness of 65mm in 1990. Deteriorations were found again around 2006 and it was decided that drastic treatment must be executed for this bridge.

A wide range of methods was considered and removal of upper-side of slab by water-jet was adopted. A method to prevent corrosions on steel bars inside concrete caused by electric potential of initial and secondary concretes were newly developed in this project. Several improvements were applied for this construction and they were considered to be applicable to other construction, which was a major contribution of this project.

## 2. OUTLINE OF THE PROJECT

After 30 years service, there were frequent reports of deterioration of Matushima viaduct (Fig. 1), such as potholes on pavement and developing cracks in the concrete of lower side of slab. The overlaid SFR concrete placed in 1990 did not work for permanent reinforcing, and the preliminary survey showed that drastic treatments must be executed to secure the functionality of the bridge. The degree of deterioration were monitored by testing core specimens taken from the slab, such as,(1) chloride contents were in the range of 1.7～3.0kg/ $m^3$ exceeding the standard value 1.2 kg/$m^3$ (this would be brought into the concrete with sand taken from sea), (2) the average of static elasticity coefficient of concrete was13.9N/$mm^2$ and the compressive strength was 22.7kN/$mm^2$ , and they were significantly lower than the design properties,

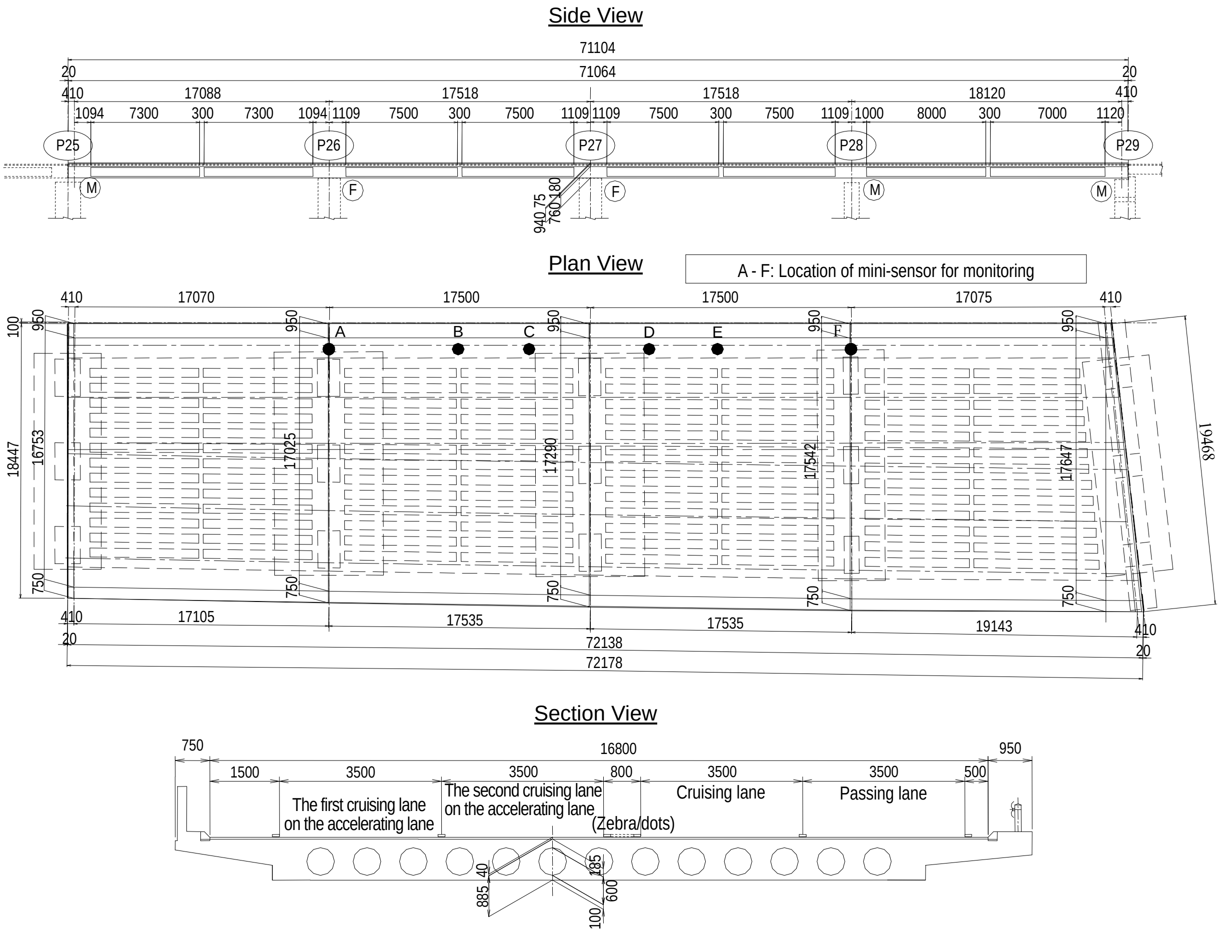


Fig. 1 Matsushima Viaduct

24N/mm$^2$ and 25kN/mm$^2$ respectively, and (3) delamination between the base concrete and overlay concrete was found in large area of the interface. The causes to weaken the strength of concrete were supposed to be micro cracks between cement and aggregates or inside of aggregates, and they were observed as shown in Fig. 2. The delamination along with the upper distribution reinforcing steel bars and deterioration of steel bars caused by macro-cell reaction were also observed as shown in Fig.3, and specially the cracks in the slab were considered to be considerably detrimental (Fig.4.), while the corrosion of steel bars were not so urgent, but countermeasures must have been introduced in this construction. The degree of ASR (Alkali-silica reaction) was also tested and it was not so serious with the result of 248$\mu$ comparing to 1000$\mu$ . Cracks of with length of more than 1,400m were found at the lower side of slab and the results of loading tests with vehicles of weight 391.6 kN were compared with structural analysis and other bridges with concluding that the deflections on mid-span were twice as large as structural analysis.


Fig.2 Crack in aggregates

Fig3. Delamination of overlaid concrete and corrosion of steel bars


Fig. 4. Delamination and vertical cracks observed at core specimens

Coincident tests were executed for other bridges and it was confirmed that Matsushima viaduct was in worse condition than any other bridges with similar history and no longer able to secure the long-term functionality to carry traffic. Understanding the urgent situation and the causes of deteriorations that must be removed through this project, the construction was planned with considering the situation of location of this bridge and reduction of total cost and environmental impacts.

## 3. EXECUTION OF RE-CONSTRUCTION

As this bridge is supporting the lanes of a ramp connecting to other roads, closing traffic of the ramp was avoided and traffic control should have been minimized. The design period of traffic control of the partial replacement plan was two months shorter than the whole replacement plan, and the amount of concrete removed to be industrial waste was 40% smaller, and the total cost was 15～20% lower, then the partial replacement plan was adopted. The design of cross section to be constructed is shown in Fig. 5. Shaving machine which has high ability to remove concrete and costs low and water-jet which has low ability to remove concrete and costs high were used. As shaving machine usually introduce micro cracks inside concrete, top 50mm of concrete was removed by shaving machine and water-jet was used to remove the initial slab to avoid micro cracks inside slab (Fig.6). This also made the total cost cheaper.

Analyzing the structure for each step of construction, it was concerned that cracks would be introduced into slab by relaxing steel bars. Therefore, during removing and placing concrete, whole slab was supported temporally (Fig. 7) and upper bars on supports were kept in non-stressed condition by jacking up to prevent cracking in slab.

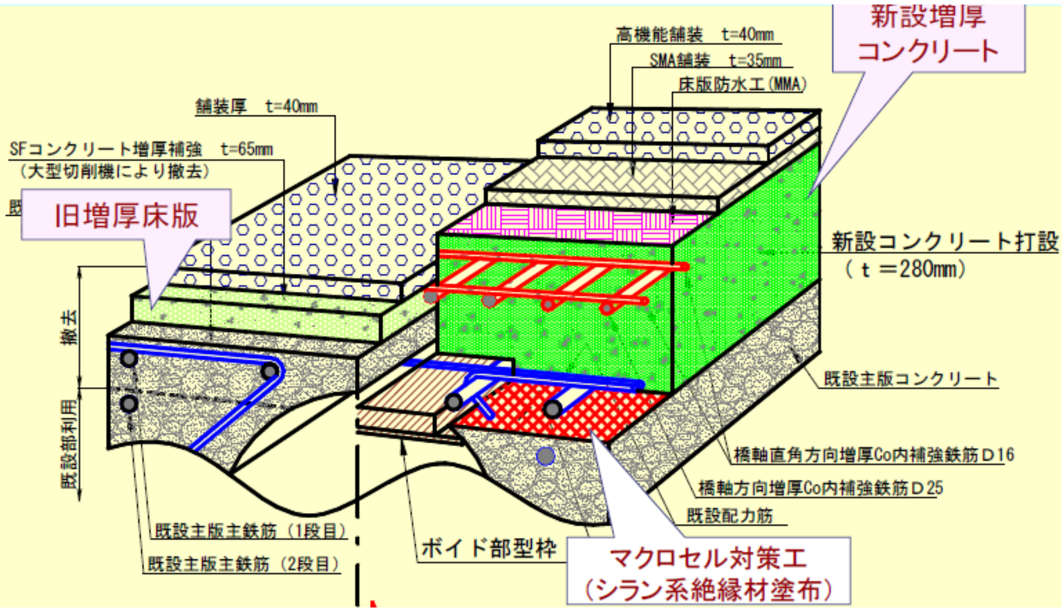


Fig. 5 Design cross section of construction

Fig. 6 Shaving (left) and Water-jet (Right)

The blue sheets and white panels shown in the right picture of Fig. 6 were used to lower the sound level and avoid splashing into traffic. Through construction, two lanes were always open for traffic and it has been done without accidents or injury.

Fig. 7. Temporal supports

## 4. DEVELOPMENT OF MACROCELL TREATMENT AND ITS EFFECT

When RC members are replaced with secondary concrete and there are high chloride content, the existing bars become anode and newly introduced bars become cathode, then the existing bars will be corroded. Corrosions of bars were observed as mentioned before the construction and it was estimated that corrosion would be escalated by this replacement. Three measures were examined in advance, (1) applying mortar paste containing nitrite lithium at the interface between initial concrete and secondary concrete, (2) applying sacrificial protection by

placing lead as positive pole and (3) applying insulator containing silane at the interface between initial concrete and secondary concrete. The method of (3) was adopted because (1) is extremely high content of nitrite lithium was required to cancel the additional chloride supply from sea and (2) requires replacement of sacrificial pole periodically, and both of them were more expensive than (3).

Accelerated exposure testing was employed to examine the effect of the countermeasures. Specimens were made and the electric resistance between the initial and secondary concrete and the electric charge of corroding were monitored for two kinds of insulator. The monitored electric resistance and the maximum value of electric charge for 4 weeks are shown below (Fig. 8)

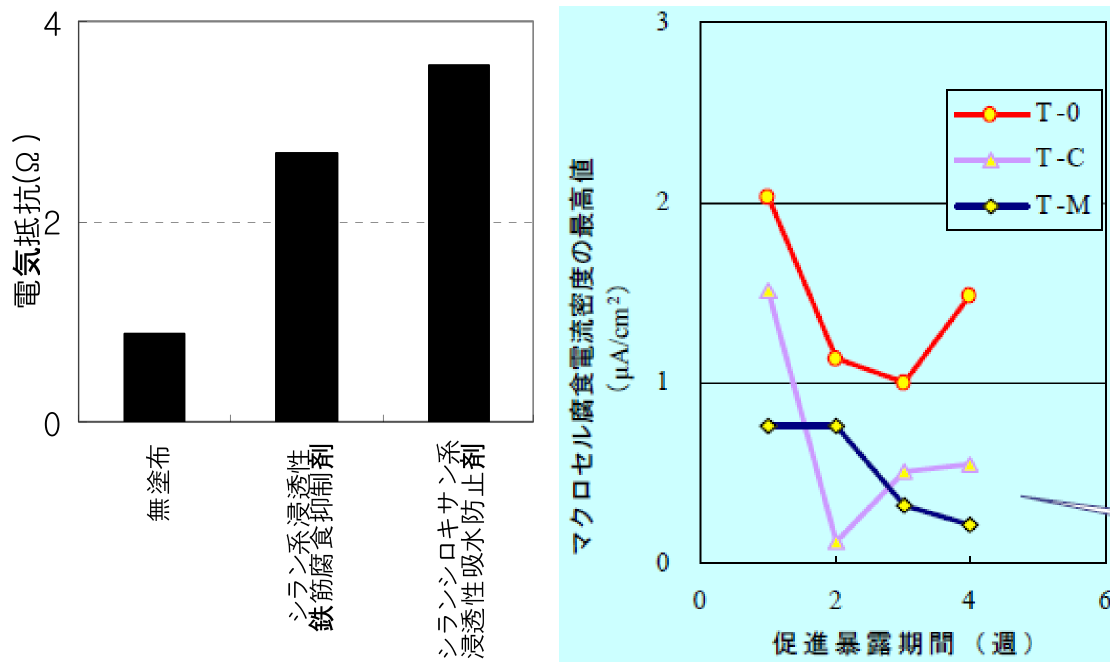


Fig. 8 Monitored electric resistance(left) and electric charge(right)

The high performance of the insulator containing silane to strengthen the electric resistance was confirmed and used in the construction. The total cost was 30% lower than conventional method. This method is now on the process to acquire the patent.

A sort of sensors were placed inside the newly placed concrete to monitor and obtain the speed of corroding of bars, and three month after the construction it showed low values enough to secure the effect of insulator.

## 5. STATIC LOAD TESTING TO CONFIRM THE STRENGTHENING EFFECT

The loading test was carried out after the construction and it was confirmed that the deflections at the middle of spans were lowered. The monitored deflections were compared with the results of structural analysis computed with the monitored Young's Modulus of concrete and the design Young's modulus, and the average of the maximum deflections of each span was almost identical to the result with design Young's Modulus (Fig. 9).

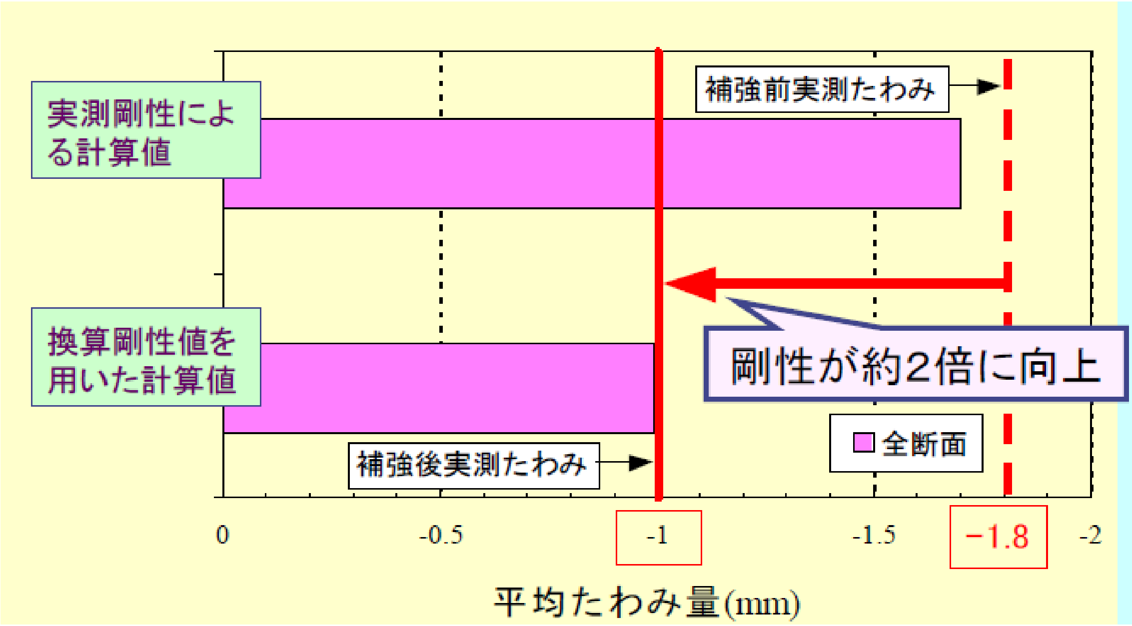


Fig. 9 Average of maximum deflection at the middle of span

## 5. Summary

The main aspects and contributions of this project are summarized as,

1. Comparing to the whole replacement plan,
   - The amount of industrial waste was reduced by 40%.
   - The total cost was reduced by 20%.
   - The period of traffic control was reduced by more than 2 months without closing traffic.
2. A method of renewal of deteriorated concrete bridge was developed without introducing micro cracks in slab by using water-jet together with shaving machine to remove concrete.
3. New method to prevent macro cell corrosion between initial concrete and secondary concrete was developed.

There are many bridges which have similar problems as Matsushima viaduct, and it is expected the methods used in this project will be applicable to them with cheaper cost and shorter duration than existing methods.